Indian J. Phys. **71B** (4), 455–463 (1997)

IJP B
— an international journal

Influence of high speed solar wind streams in the long-term modulation of cosmic rays

Achyut Pandeya
Department of Physics, Govt Model Science College, Rewa-486 001, Madhya Pradesh, India
Pankaj Kumar Shrivastava
Department of Physics, Govt. New Science College, Rewa-486 001, Madhya Pradesh, India
I Sabbah and M A El-Borie
Department of Physics, Alexandriya University, Alexandriya, Egypt

Received 16 October 1996, accepted 4 April 1997

Abstract : High speed solar wind streams can be distinguished into two kinds originated from two different sources. The first kind is a long lasting high speed solar wind streams emitted by coronal holes that exhibit an apparent tendency to recur at intervals of ~ 27 days the so called corotating streams- and the second one, characterized by lower solar wind streams to be associated with strong active regions emitting solar flares are called as flare generated streams These two types of streams produce significantly different effects on the cosmic ray intensity on short-term as well as on long-term basis In this analysis, we try to explain the long-term variations of the cosmic ray intensity on the basis of short-terms transient variations for the interval 1979 to 1990. Daily mean of one low and middle-latitude set of neutron monitor data have been analysed to observe average behaviour of cosmic ray intensity on short-term basis, using the chree method of superposed epoch for the period 1986–1990 It has been found that flare-generated streams are significantly responsible in producing 11-year cyclic variation in cosmic ray intensity

Keywords : Cosmic rays, solar wind, solar activity

PACS Nos. : 96 40.Kk, 96 50.Ek

1. Introduction

The solar activity is generally represented by the magnitude of the sunspot number though sometimes the 2800 MHZ solar radio flux, solar flares are also used. The long-term modulation of the cosmic ray intensity is significantly correlated with these solar parameters. Interplanetary parameters such as solar wind velocity, proton temperature and density, B, Bz, components of Interplanetary Magnetic field are also associated with cosmic ray modulation. However, it has been generally found that none of these parameters can uniquely predict the observational features either on a long-term basis or on a short-term basis. It has been felt during the earlier studies of cosmic ray modulations, the global structure of the heliospheric magnetic field and current sheet, solar activity and cosmic ray intensity are all temporally correlated, and it is difficult to extract casual relationship from positive correlation. Influence of solar outputs on high energy galactic cosmic ray particles were discovered about forty years back. Since then much work has been carried out on the subject, but many unsolved problems are still present in cosmic ray physics, particularly, the long-term (11-year) variation of cosmic ray intensity [1–3]. Transient cosmic ray diminution of short durations (3 to 10 days) are more abundant and during that period, the minimum cosmic ray intensity of 11-year solar cycle is observed. It has been suggested that the accumulative effect of the observed transient diminution can explain the 11-year modulation in cosmic ray intensity [4]. However, quantitatively, it has not been found easy to ascertain the relative role of the effect of different types of interplanetary disturbances propagating from Sun to the heliospheric boundary on the cosmic ray particles. Therefore, the association of average solar wind speed with the long-term modulation of cosmic ray has no relevance due to different nature of the two types of high speed solar wind streams [5–7]. Solar wind velocity is one of the main factors in the convection-diffusion approximation to the transport equation, which determine the modulation of cosmic ray intensity. On the basis of this equation and mechanism short-term large fluctuation in solar wind speed ought to produce discernible changes in cosmic ray intensity. Mavromichalaki *et al* [8] have separated high speed solar wind streams into two categories : the corotating or coronal hole associated streams (CS) and the flare-generated streams (FGS) on the basis of their solar source and different characteristics such as fluctuation in magnetic field, proton temperature and density. Recently, Shrivastava and Shukla [9] studied the effects of these two types of high speed solar wind streams on the cosmic ray intensity for the period 1980–1986, the descending phase of Solar Cycle 21. They observed that the sudden storms commencement (SSC) associated with flare-generated streams, produce significant lowering in cosmic ray intensity on short-term basis. In this work, the study has now been extended to cover the recent period 1986 to 1990, the ascending phase of Solar Cycle 22, and these short-term transient variations are incorporated to explain the 11-year cosmic ray intensity variations.

2. Method of analysis

We have separated the two types of high speed solar wind streams on the basis of the same criteria as reported in earlier studies [9]. Adopting the above criteria and using the plots of hourly values of interplanetary parameters [10–14], we have selected zero epoch days which satisfy the following conditions :

(i) The solar wind speed should persist at high values atleast three days after it begins to increase.

(ii) The solar wind speed (V) should increase substantially over a short period ($\Delta V \gtrsim 200$ Km S^{-1} in $\lesssim 24$ hr), reaching a maximum value of $\gtrsim 500$ Km S^{-1}.

(iii) No Forbush decrease (FD) of magnitude $\gtrsim 3\%$ in cosmic ray intensity should occur within the – 5 to + 10 days of the zero day. This restriction is to avoid their influence on the result of this analysis. We have adopted the chree method of superposed epoch to determine the average behaviour of cosmic ray intensity. Daily mean values of cosmic ray intensity of Hermanus (4.55 GV) and Tokyo (11.50 GV) Neutron monitor stations have been used in the analysis for the period of 1986 to 1990. The magnitude of deviations for the period 1980–85 have been taken from the diagrams of Shrivastava and Shukla [9]. The magnitudes of the cosmic ray deviations are derived by using the daily mean of cosmic ray data (neutrons) for sixteen days, five days prior to zero day (starting day, when solar wind begins to increase) and ten days after the zero day. We have applied the following equations to derive the percent deviation of cosmic ray intensity for each day

$$\text{Deviation from sixteen days mean} = \frac{\text{Daily mean of cosmic rays}}{\text{Sixteen days mean of cosmic ray}} \times 100,$$

$$\text{Percent deviation} = 100 - \text{Deviation from mean},$$

$$\text{Magnitude of deviation (\%)} = \text{Sum of sixteen days percent deviation.}$$

3. Results and discussion

Earlier studies on solar wind streams and cosmic ray transient variations are based on the dominance of coronal hole associated streams during low solar activity period and the dominance of flare-generated streams during high solar activity period [15]. In this analysis, our aim is to observe the effects of these two types of high speed solar wind streams for the period of 1986 to 1990, which cover the ascending phase of Sunspot cycle 22. A number of large diminutions in cosmic ray intensity (Forbush decreases) and abrupt increases in cosmic ray intensity (Ground level enhancements) are reported during this period, which indicate the disturbed condition of interplanetary medium. Results of transient variations from 1979 to 1990 are important for us to explain the long-term cosmic ray modulation. Figure 1 shows the number of two types of high speed solar wind streams identified during the different phases of solar activity cycles 21 and 22. It is seen in Figure 1 that the corotating streams dominate during the low solar activity years and are found in maximum numbers than flare-generated streams for all the years. We have done chree analysis of superpose epoch for the period of 1986 to 1990 to determine the average behaviour of short-term changes in cosmic ray intensity. The results of chree analysis are plotted in Figure 2 for all the selected events using the daily mean values of Hermanus and Tokyo Neutron monitors. The plots refer to the percent deviation of the daily mean count rates of the appropriate cosmic ray data. It is to be pointed out that for each event, the cosmic ray intensity is first averaged for 16 days from – 5 to + 10 days with zero epoch days and this average is used to calculate the percentage deviations for each day. It is noted that the average behaviour of cosmic ray intensity differs in its magnitude of deviation from year to

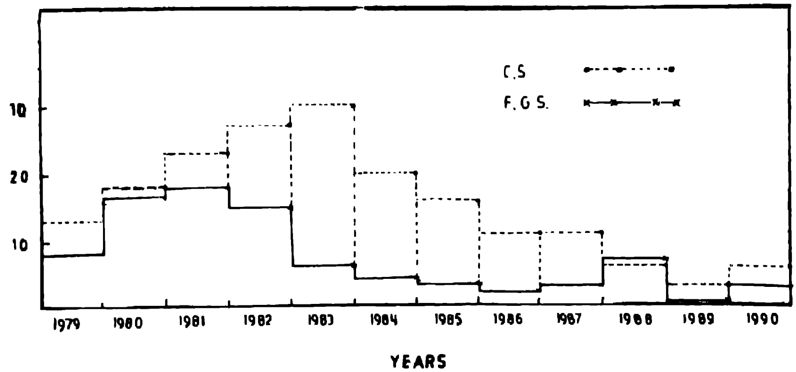

Figure 1. Histograms showing the distribution of the number of flare-generated streams (F.G.S.) (solid line) and corotating streams (C.S.) (dash line) for the period 1979–1990

year. Almost flat variations are significantly noticed during the years of minimum solar activity period. However, some diminutions are apparent during the high solar activity years. This indicates some unnoticed features during high Sunspot years, which are capable in producing short-term depression in cosmic ray intensity. Now, we have separated the high speed solar wind streams into two categories and done the statistical analysis to determine the influence of both types of high speed solar wind streams on cosmic ray intensity for ascending phase of solar activity cycle 22. The results of chree analysis for days – 5 to 10 days have been plotted in Figure 3, as percent deviation of the data from the Hermanus Neutron monitor (4.55 GV). During each year from 1986 to 1990, large diminutions in cosmic ray intensity for flare-generated high speed solar wind streams are registered with magnitude ≈ 0.8%. Not a single flare-generated stream has been considered for analysis for the year 1989, due to its association with large Forbush diminutions and Ground level enhancements. Results of similar analysis for Tokyo neutron monitor, a low latitude station, have been shown in Figure 4. The results are similar as obtained in Hermanus neutrons. During the years 1986 to 1987, we note almost similar time-behaviour as well as an equal magnitude of the diminutions for the two neutron monitors situated at two different latitudes on the earth surface. In contrast, it is to be emphasized that during 1988–1990, a differential effect in the intensity in the neutron monitors is clearly observed.

We attribute this to the difference in the rigidity response of cosmic ray neutron monitors. The above difference in cosmic ray deviation for two neutron monitors, confirms rigidity (energy) dependence of cosmic ray particles for the high solar activity period of Sunspot cycle 22. Analysis reveals that high energy cosmic ray particles always reach in less number on the earth surface during the time of flare-generated streams. Magnetic fields of

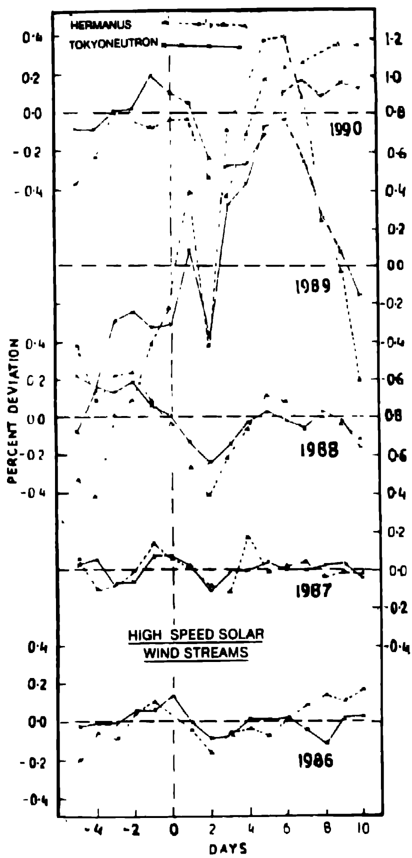

Figure 2. The results of chree analysis of superposed epoch from –5 to 10 days with respect to zero epoch days The percent deviations of the daily mean cosmic ray intensity of Hermanus and Tokyo neutron monitors have been used. Zero day corresponds to the starting day of the high speed solar wind streams.

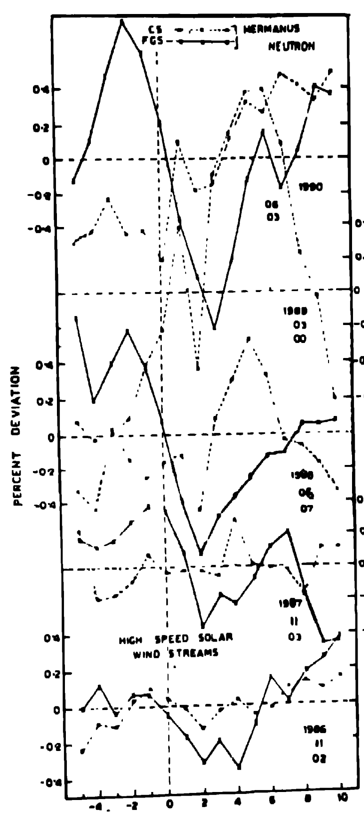

Figure 3. Same as in Figure 2 for Hermanus neutrons, when the high speed solar wind streams are separated into two categories · (i) corotating streams, and (ii) flare-generated streams

interplanetary medium are generally found to be enhanced during the period of high solar activity and particularly during the time of flare-generated streams which in turn, responsible for scattering of cosmic ray particles. We observe insignificant variation in CR intensity during the time of corotating streams, which is in agreement with the mechanism that the diffusions coefficient is reduced in the corotating interaction region. The interaction between slow and fast solar winds creates a corotating interaction region (CIR) of compressed, heated plasma at the leading edge of the high speed streams. Hence, it is assumed that the high speed solar wind streams coming from coronal holes are observed to be less effective in modulating the cosmic rays than the high speed streams coming from the active parts of the Sun. Yearly averages of cosmic ray intensity (Tokyo) alongwith

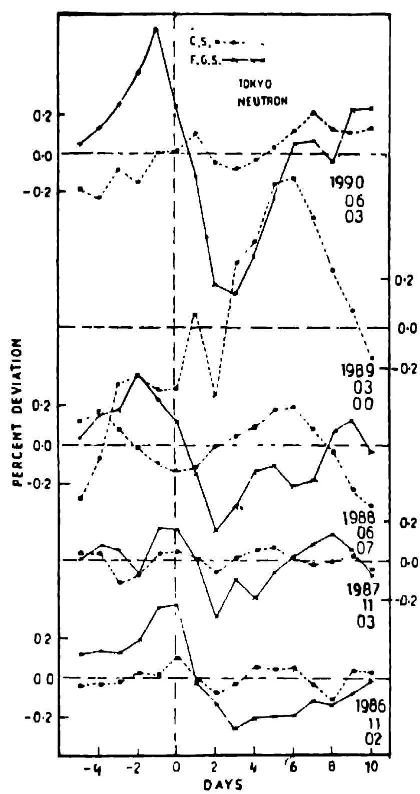

Figure 4. Same as in Figure 3 for Tokyo neutrons.

Sunspot numbers for the period 1979 to 1990 are plotted in the top of Figure 5. In the middle of the Figure 5, the magnitude of cosmic ray deviations are plotted during the period of flare-generated streams. Magnitude of cosmic ray deviations are shown in three different categories (i) Pre-five days, (ii) First post-five days and (iii) Last post-five days. Zero day is taken as the starting day of high speed solar wind streams. Previous five days from the zero days are called the pre-five days. We can say ten days after zero days as post-ten days.

The post-ten days interval is divided into two equal periods. The first five days after zero day are called the first post-five days. Rest of the five days are called as last post-five days.

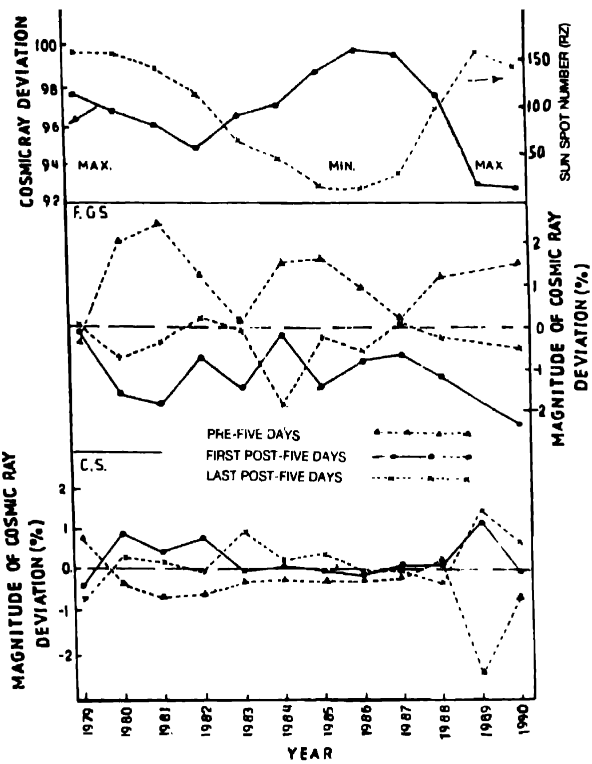

Figure 5. Long-term linear diagram which shows magnitude of cosmic rays deviation in three categories : (i) Pre-five days from starting day of high speed solar wind streams, (ii) First post-five days from zero day, and (iii) Last post-five days from zero day. Zero day is taken as a starting day of high speed solar wind streams. First post-five days and last post-five days are the two equal five days interval of ten days, which are counted after zero day Magnitude of deviation of cosmic ray intensity in percentage are shown in lower and middle blocks by the number (0, ± 1, ± 2).

Three categories of magnitude of cosmic ray deviations for corotating streams are plotted in the bottom of Figure 5. We observe significant minimum values of magnitudes of cosmic ray deviation during the period of first post-five days for the entire interval of 1979 to 1990, which covers the maximum periods of solar cycle 21 and 22. We also noted that decrease in the magnitudes is much larger during the period of maximum solar activity. Almost constant behaviour in magnitude of deviation in cosmic rays is seen for all the years of Sunspot cycle (1979 to 1990) except in 1989, which is known as the abnormal year in solar cycle 22. This analysis indicates accumulative effect of flare-generated streams on cosmic ray intensity, which has significant influences on the magnitude of cosmic ray intensity on long-term basis. It has been shown in the present work that the temporal changes (from year to year) of the magnitude of decrease in cosmic ray intensity during post-five days from starting day of flare-generated high speed solar wind streams play significant role in producing 11-year or long term modulation of galactic cosmic rays.

4. Conclusions

The transient decreases in cosmic ray intensity during first post-five days, due to flare-generated high speed solar wind streams (FGS), are found larger than the corotating streams. The deviations have also been found much larger during the high solar activity years. Flare-generated high speed solar wind streams, which during the 11-year cycle of solar activity vary significantly, are also found to be responsible in the eleven-year (long-term) variation of cosmic rays.

Acknowledgments

The authors thank Dr. P H Stoker of Potechefstrom University, South Africa for Hermanus Neutron Monitor data and Prof. K Takashashi, E Sakamato of Cosmic Radiation Laboratory, Harosawa, Japan for Tokyo neutron data. We are also grateful to J.H.King of W.D.C.A. (USA) for interplanetary medium data. This research work was supported in part by the University Grants Commission, CRO, Bhopal for Grant No 13-54/(MRP/CRO). We thank Dr. Ravindra P Shukla, FSL, Rewa for several discussions.

References

[1] D Venkatesan, A K Shukla and S P Agrawal *Solar Phys.* **120** 145 (1982)

[2] N Iucci, M Parisi, M Storini and G Villoresi *Neuvo cim.* **2c** 421 (1979)

[3] P K Shrivastava *Proc. 21st Int Cosmic Ray Conf* **6** 65 (1990)

[4] J A Lockwood and W R Webber *J. Geophys Res* **89** 17 (1984)

[5] Y Munakata, S Mori, J Y Ryu, S P Agrawal and D Venkatesan *Proc. 20th Int Cosmic Ray Conf* **4** 39 (1987)

[6] B L Mishra, P K Shrivastava and S P Agrawal *Proc. 21st Int Cosmic Ray Conf* **6** 299 (1990)

[7] P K Shrivastava and S P Agrawal *Proc Basic Plasma Processes on the Sun* (Holland : Kluwar Academy) Holland p 259 (1990)

[8] H Mavromichalaki, V Vassilaki and E Marmatsouri *Solar Phys.* **115** 345 (1988)

[9] P K Shrivastava and R P Shukla *Solar Phys.* **154** 177 (1994)

[10] J King *Interplanetary Medium Data Book–Suppl 2, 1978–1982* NSS SCD/VDC-A (Goddard Space Flight centre, Greenbelt, MA) (1983)

[11] J King *Interplanetary Medium Data Book–Suppl. 3,* NSS D/WDC-A (Goddard Space Flight Centre, Greenbelt, MA) (1986a)

[12] J King *Interplanetary Medium Data Book–Supplement 3A, 1977-1985* **NSS CD/WEDC-A** (Goddard Space Flight Centre Greenbelt MA) (1986b)

[13] J King *Interplanetary Medium Data Book–Supplement 4, 1985–1988* **NSSCD/WDC-A** (Goddard Space Flight Centre, Greenbelt, MA) (1989)

[14] J King and N F Papitashesli *Interplanetary Medium Data Book–Supplement 5, 1988–1993* **NSSCD/WD-CA** (Goddard Space Flight Centre, Greenbelt, MA) (1994)

[15] J B Zirker *Rev Geophys Space Phys* **15** 247 (1977)